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# Multi-level Recording in Erasable Phase-Change Media

## by Light Intensity Modulation

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### ABSTRACT

Multi-level recording has advantage of increasing the recording density without extensively altering the current optic configuration. In this paper, a new four-level recording phase-change disk using three-recording layers was demonstrated. By modulating the intensity of the laser pulse, marks were chosen to record in any of recording layers, to form four recording regions. Utilizing the property of the phase change media whose amorphous and crystalline states differ largely in refractive indices, each recording region corresponds to different reflectance. For the four-level recording disk, each recording region represents two-bit data, then the recording density of the four-level disk is a factor of two higher than that of a conventional disk recorded by adopting the pulse position modulation (PPM).

**Keywords:** light intensity modulation, multi-level recording optical disk, pulse position modulation, multi-layer

### 1. INTRODUCTION

Recording density of optical disks is limited by the optical diffraction limit. For a conventional disk whose marks are recorded by the pulse position modulation (PPM) method, each mark length corresponds to one bit. With the multi-level recording method, each recording region of the four-level disk corresponds to two-bit data. Therefore, the effective mark length for one bit is half of the actual mark length, and the recording density can be doubled without using the short wavelength diode laser or high numerical aperture (N.A) lens. Several multi-level recording methods have been reported. For example, the magnetic multi-valued (MMV) recording was realized in MO media, applying an exchange coupled bi-layer<sup>[1]</sup>. Using partial crystallization properties of phase-change optical disks to achieve multi-level recording was also reported<sup>[2]</sup>. In this paper, a new four-level recording technique on the three-recording layers disk was demonstrated.

### 2. PRINCIPLE AND DISK DESIGN

The four-level optical disk structure (Substrate /ZnS-SiO<sub>2</sub> /1st recording layer /ZnS-SiO<sub>2</sub> /2nd recording layer /ZnS-SiO<sub>2</sub> /3rd recording layer /ZnS-SiO<sub>2</sub> /Al) is composed of three recording layers. All of the recording layers are composed of phase-change material GeTeSb of the same composition, as shown in Fig. 1. Marks can be recorded in any of recording layers. The dielectric layers of ZnS-SiO<sub>2</sub> are used to control the reflectance and the thermal diffusion of the four-level disk. The Al reflective layer increases the cooling rate of the recording layers, and is as a reflector to optimize write/read properties.

The amorphous and crystalline states of the recording layer correspond to different refractive indices. The total reflectance of the disk is different when the recording layers are in the different phase. Four different reflectance, R<sub>ccc</sub>, R<sub>acc</sub>, R<sub>aac</sub>, R<sub>aaa</sub> of the four-level disk are produced, as shown in Fig. 2. For example, R<sub>acc</sub> denotes the reflectance when the upper recording layer is in the crystalline state, and the middle recording layer and lower recording layer are in the amorphous state, respectively.

Four recording regions, ccc, acc, aac, aaa are formed by using the different laser power to write marks in different recording layers. Each recording region represents two bits, as shown in Fig. 3(a). All recording layers should be initialized

to the crystalline state, as phase change disks, before to record amorphous marks. In the recording process, the laser beam is incident from the substrate. Most energy is absorbed by the 1st recording layer so that the temperature of the irradiated region of the 1st recording layer is higher than that of the 2nd and 3rd recording layers. The temperature of the 2nd recording layer is also higher than that of the 3rd recording layer. The amorphous state can be formed when the irradiated regions of the recording layer are heated over the melting point, then cool down rapidly. By controlling the laser power, the highest temperature of each recording layer is different, and the marks can be chosen to record in the different recording layers, as shown in Fig. 3(b). For example, in order to record marks only in the 1st recording layer, the irradiated region of the 1st recording layer is over melting point; meanwhile, the temperature of other two recording layers are lower than melting point. Thus, the amorphous marks are only recorded in the 1st recording layer.

The temperature difference between any two recording layers, which is controlled by the disk structure, should be high enough to avoid recording marks on the unexpected recording layers. By increasing the thickness of the dielectric layers between any two recording layers, the power margin of recording marks in different recording layers will be increased because of higher temperature difference. However, the mark size difference between any two recording layers will also be enlarged due to the effect of extensive heat diffusion. It will affect the quality of the readout signal. Therefore, there is a tradeoff between the power margin and the mark size.

The temperature profile of the recording layers need to be carefully controlled. By adopting single pulse writing, the highest temperature of the rear part of the recorded mark is higher than that of the front part of the same recorded mark due to the heat diffusion along the direction of the laser spot scanning. It may cause those marks be recorded in the unexpected recording layers. To decrease the effect of the thermal diffusion, a multi-pulse recording method<sup>[3]</sup> was utilized, as shown in Fig. 4.

When the focussed laser spot scans along the track, different recording regions produce different reflectance levels, as shown in Fig. 5. The C/N of the four-level disk is defined at the nearest interval of reflectance levels. The contrast of any two reflectance levels of the readout signal is determined by the reflectance of the disk and the recorded mark size. When the recording density increases, the reduced recorded mark size decreases, so does the readout signal. In order to achieve high signal quality, the reflectance contrast between each level needs as high as possible. With the optical simulation using the Jones matrix method<sup>[4]</sup>, the reflectance was defined by controlling the thickness of each layer of the disk.

According to the optical and thermal simulations, the disk structure of (Substrate / 150nm ZnS-SiO<sub>2</sub> / 8nm 1st recording layer / 40nm ZnS-SiO<sub>2</sub> / 8nm 2nd recording layer / 12nm ZnS-SiO<sub>2</sub> / 7nm 3rd recording layer / 50nm ZnS-SiO<sub>2</sub> / 40nm Al) is designed for the experiments. The simulated reflectances of the four-level disk, R<sub>ccc</sub>, R<sub>acc</sub>, R<sub>aac</sub>, R<sub>aaa</sub> are 0.24, 0.03, 0.09, 0.18, respectively.

### 3. EXPERIMENT AND DISCUSSION

The optical and thermal designed four-level disk was measured by a dynamic tester. The wavelength is 660nm and N.A is 0.6. The linear velocity of the disk is about 4.8m/s.

When the recorded mark size of the four-level disk was about 0.8μm, four recording regions were produced by different multi-pulse waveform, as shown in Fig. 6. The readout signal with the DC-read detection method was observed, as shown in Fig. 7. When the recording pattern was arranged as Fig. 7(b), the readout signal of four reflectance levels was no longer detectable.

The pulse-read detection method<sup>[5]</sup> to distinguish the four reflectance levels was adopted. The readout signal of the same recording pattern as shown in Fig. 7(b) was tested by the pulse-read method, as shown in Fig. 8. The four-level readout signal can be clearly differential. When the recorded marks became smaller than 0.6μm, the readout signal was distorted and the reflectance level corresponding to each region no longer kept the original level, as shown in Fig. 9. Thus, the smallest recording region which was detectable in this four-level disk was about 0.6μm using the above mentioned optical system, laser, and light intensity modulation writing method.

The C/N of the four-level disk is defined at the nearest interval of reflectance levels which is between the acc and aac regions in the experiment, as shown in Fig. 10. The C/N of the four-level disk for different effective mark size, half of the actual mark length, is compared to a conventional disk, as shown in Fig. 11. The C/N of the four-level disk for the actual mark size of 0.6μm which corresponds to the effective mark size of 0.3μm was about 36dB. It shows that the C/N of the

four-level disk for the small effective mark size was higher than that of the conventional disks. The C/N was not high enough for the large mark size because the contrast between the reflectance levels of acc and aac regions was small, and adjacent marks interfered with each other.

#### 4. CONCLSION

Multi-level recording using the light intensity modulation method on the four-level disk of three erasable phase change recording layers was studied. Multi-level recording has advantage of increasing the recording density without altering the current optic configuration. At the laser wavelength of 660nm and N.A of 0.6, the C/N for the effective mark size of 0.3um on the four-level disk is above 36dB by light intensity modulation recording. The C/N can be increased further by optimizing the structure of the disk and the writing schemes.

#### 5. ACKNOWLEDGEMENT

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Substrate
dielectric layer ( $\text{ZnS-SiO}_2$ )
1st recording layer ( $\text{Ge}_{21}\text{Te}_{53}\text{Sb}_{26}$ )
dielectric layer ( $\text{ZnS-SiO}_2$ )
2nd recording layer ( $\text{Ge}_{21}\text{Te}_{53}\text{Sb}_{26}$ )
dielectric layer ( $\text{ZnS-SiO}_2$ )
3rd recording layer ( $\text{Ge}_{21}\text{Te}_{53}\text{Sb}_{26}$ )
dielectric layer ( $\text{ZnS-SiO}_2$ )
reflective layer ( $\text{Al-Cr}$ )

Fig. 1 The structure of the four-level recording using erasable phase change media

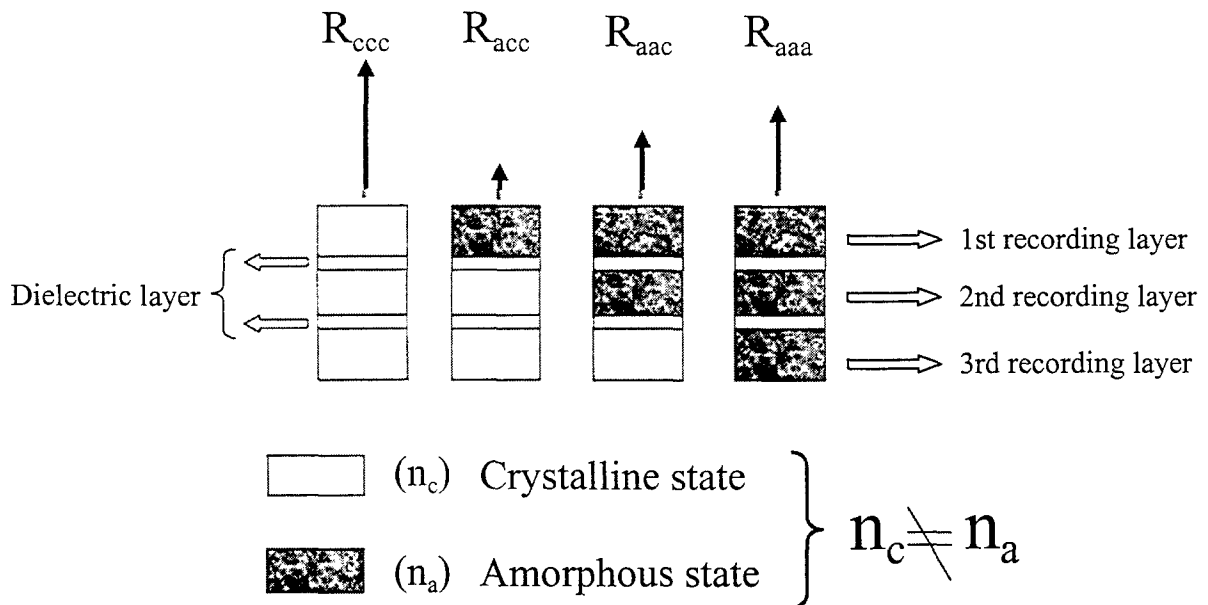
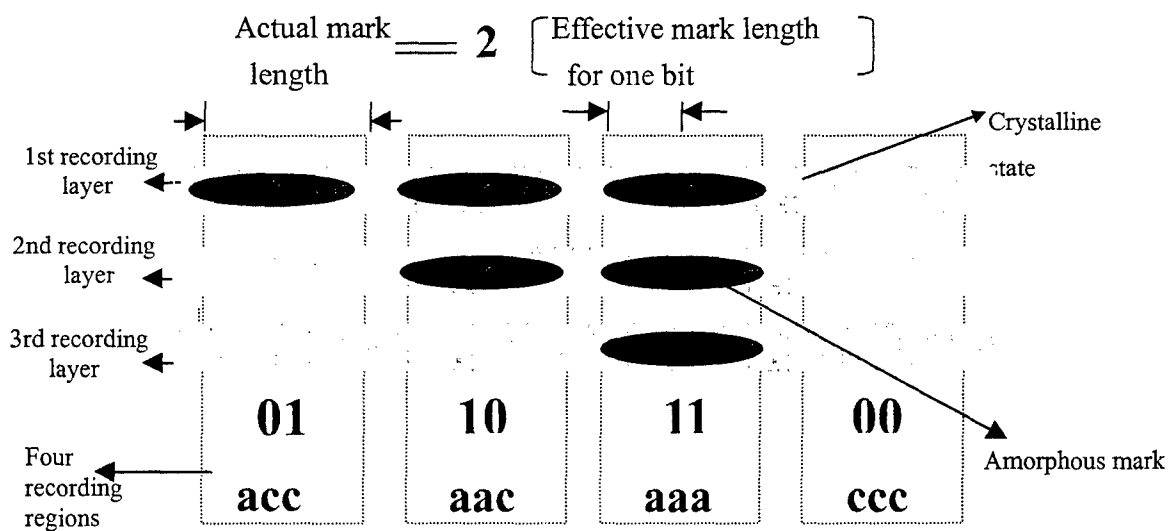
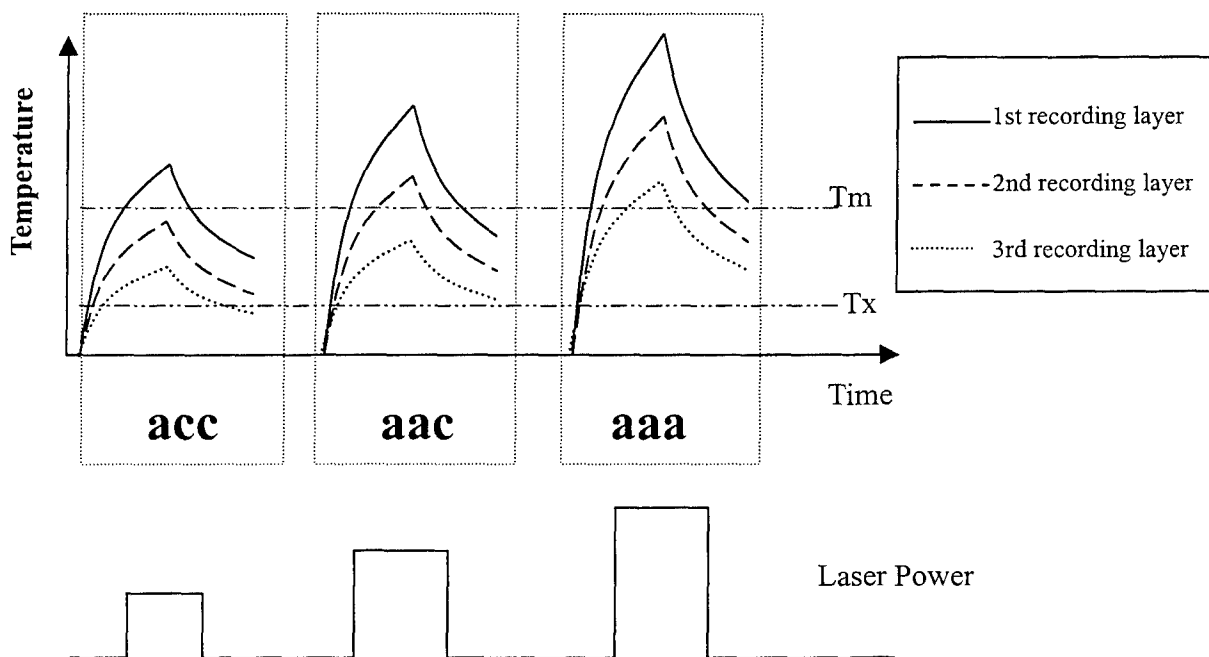


Fig. 2 Four different reflectances of the disk when both recording layers are in the different phase states.



(a)



(b)

Fig. 3 (a) Four different recording regions, acc, aac, aaa, ccc. (b) Temperature profiles on the recording layers at different recording power to produce different recording regions. Tx and Tm are the melting and crystallize temperature, respectively.

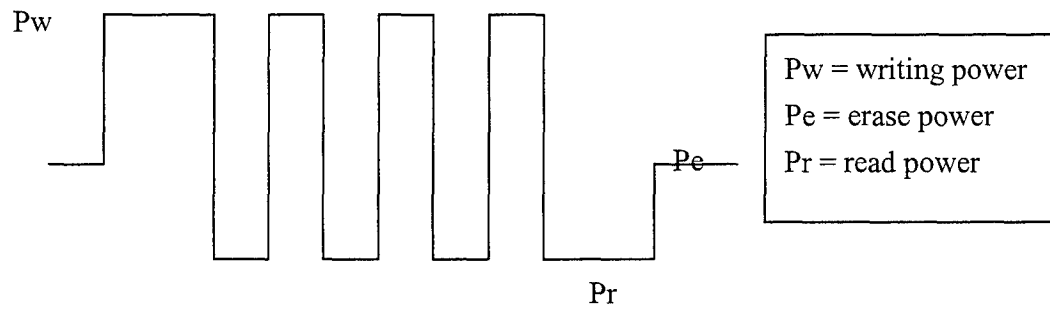


Fig. 4 Multi-pulse recording waveform.

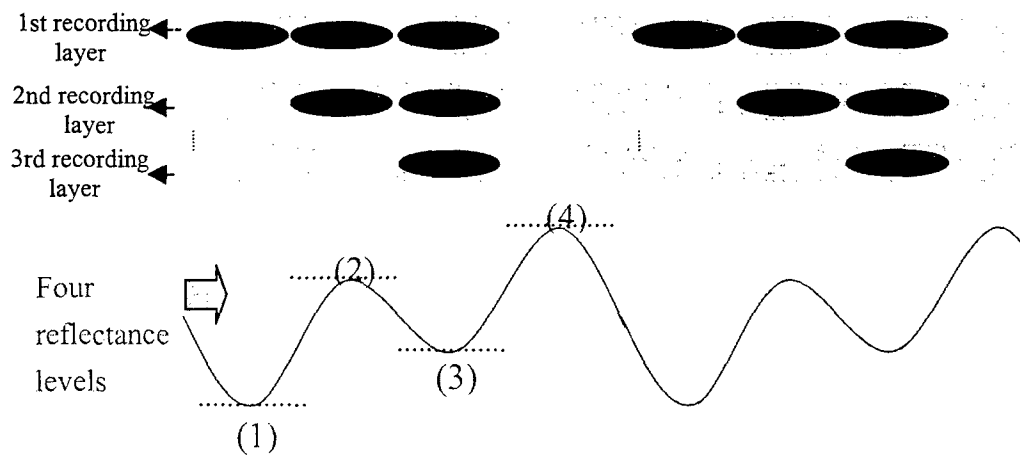


Fig. 5 The readout signal of the disk of four reflectance levels.

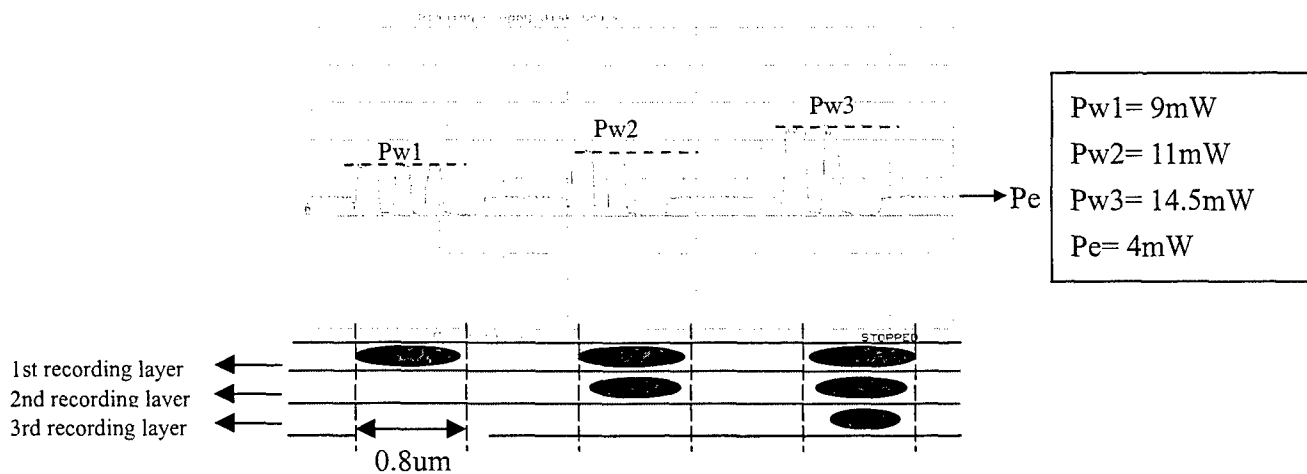


Fig. 6 When the recorded mark size is about  $0.8\mu\text{m}$ , the different recording regions are produced by pulse readout method.

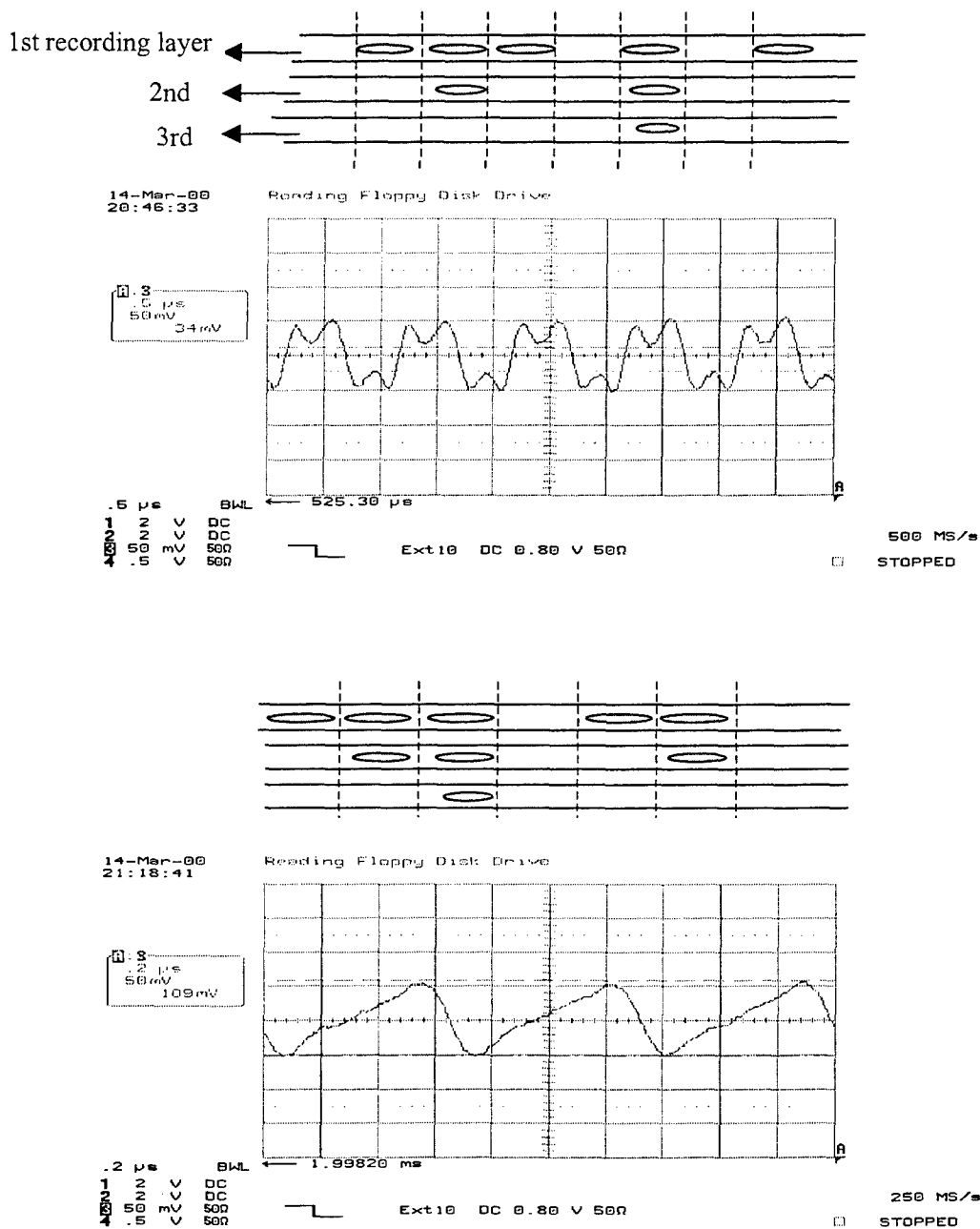


Fig. 7 (a) The readout signal of the repetitive recording regions with the DC-read detection when the mark size is about 0.8 $\mu$ m. (b) The readout signal of the different recording pattern.



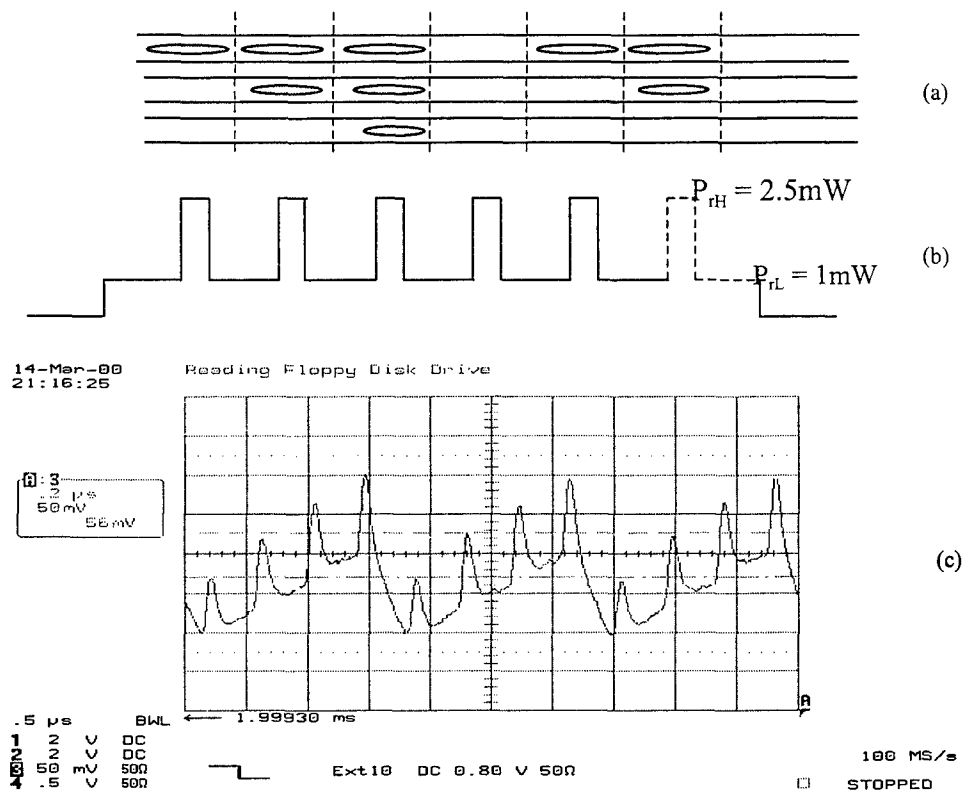


Fig. 8 (c) The readout signal of the repetitive recording regions with (b) the pulse-read detection (a) when the mark size is about  $0.8\mu\text{m}$ .

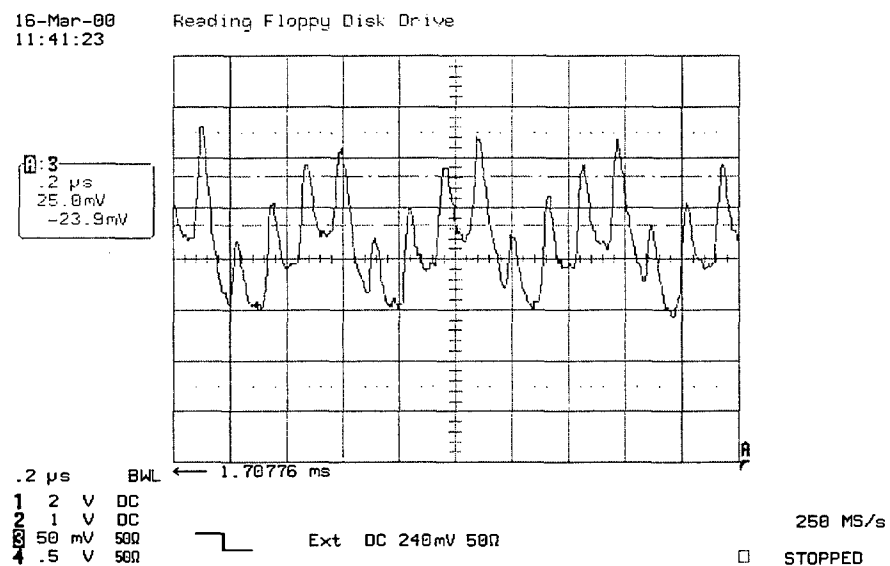


Fig. 9 The readout signal with the PULSE-read detection when the mark size is about  $0.6\mu\text{m}$ .

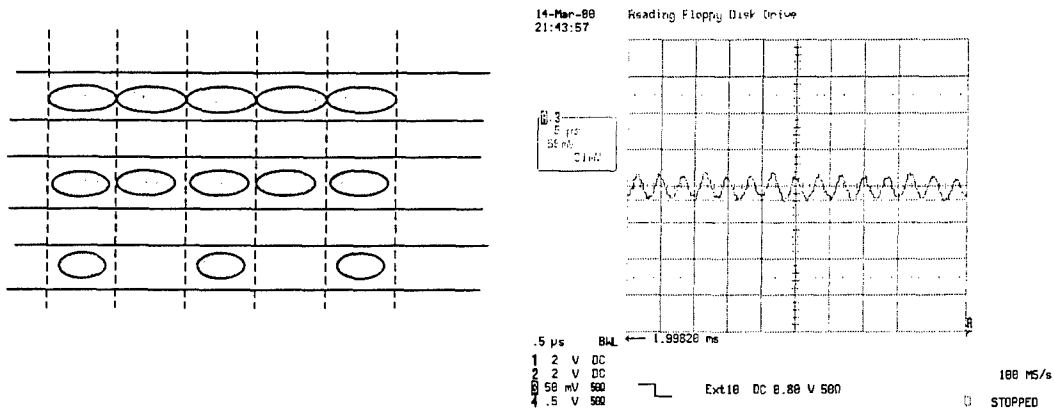


Fig. 10 The C/N of the four-level disk is measured with this repetitive recording pattern.

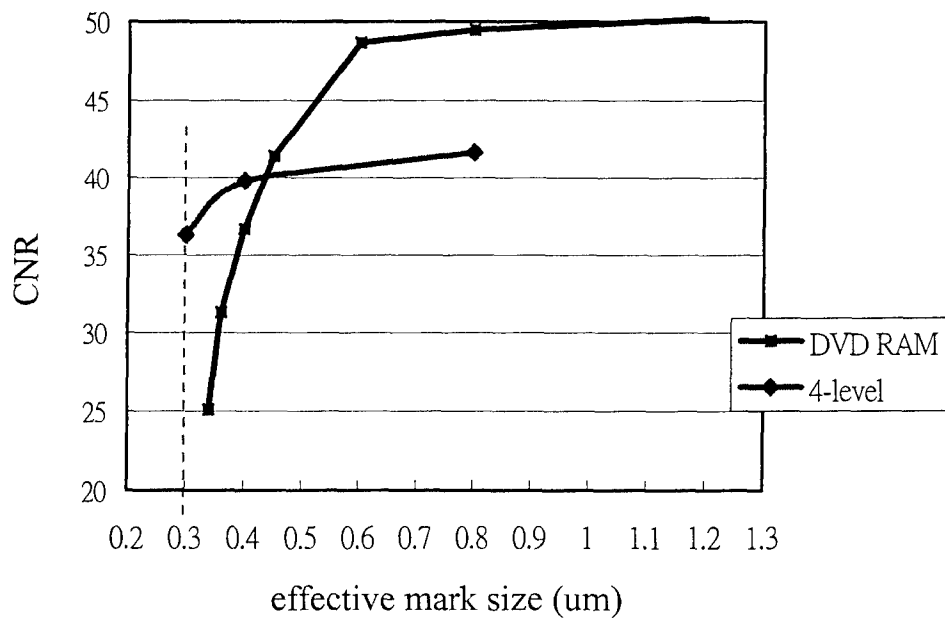


Fig. 11 C/N as a function of the effective mark length in a four-level disk and a conventional disk.